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AN AUTOMATED ENERGY BILL METERING SYSTEM BASED ON GSM TECHNOLOGY

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ABSTRACT

The measurement of the energy consumed by residential and commercial buildings by utility provider is important in billing, control, and monitoring of the usage of energy. Traditional metering techniques used for the measurement of energy are not convenient and is prone to different forms of irregularities. These irregularities include meter failure, meter tampering, inaccuracies in billing due to human error, energy theft, and loss of revenue due to corruption, etc. This research study proposed the design and construction of a microcontroller-based electric energy metering system using the Global System for Mobile communication (GSM) network. This system provides a solution to the irregularities posed by the traditional metering technique by allowing the utility provider have access to remote monitoring capabilities, full control over consumer load, and remote power disconnection in the case of energy theft. Proteus simulation software was used to model the system hardware and the software was obtained by using embedded C programming and visual basic. It was observed that the system could remotely take accurate energy readings, provided full control over consumer loads and execute remote disconnection in case of energy theft. The system provides high performance and high accuracy in power monitoring and power management.

Keywords: Power system, metering system, GSM, and Energy theft.

INTRODUCTION

Energy meters are electronic instruments used to measure the amount of electric energy used by consumers in a circuit within a residential areas, industry or business at any given time.

Existing challenges with the traditional metering system include meter failure, vendor fraud through energy theft and meter tampering (Kambule *et al.,* 2018). The effect of these challenges reduces the efficiency of electricity transmission globally. In Nigeria, the combination of technical and commercial losses in the power sector sum up to about 75% losses within the sector. However, large percentage ranging between 50-60% of these losses is attributed to energy theft

(Obadote, 2009; Nizar and Zhao, 2006). Researchers have made continuous effort to reduce these losses, hence advancing into the development of electric energy meters in the last decade (Hasbullah, 2012). The conventional electromechanical meters are being replaced by new electronic meters to improve accuracy in meter reading thus leading to the development of automatic metering system (NARUC, 2007).

Automatic Metering System (AMS) are regarded as smart metering system with a technology that gathers data from metering devices and sends it to a master station for real-time billing purposes (Arora and Taylor, 2016). The data from these devices are obtained remotely without the need to physically access the metering device (Hasbullah, 2012) through wired or wireless technologies (Adekunle, 2012; Chu and Hogg, 2000). The wired technology includes the use of Power line carrier, coaxial cables, pilot cables, etc. for data transmission from the consumer end to the utility station while the wireless technology is widely used due to its high data speed and transmission range examples include the use of Global System for Mobile Communication (GSM) technology, WIFI, etc. (Dhok and Deshmukh, 2014). Some of the unique features of smart meter include: time-based pricing, providing consumption data for consumer and utility, net metering, failure and outage notification, energy theft detection etc.(Ramyar *et al.,* 2014).

The motivation of this study is based on the existing challenges with energy systems in Nigeria such as: Inaccuracies in generating billing information due to corruption or human error, difficulty in accessing home energy meters, high level of theft resulting in loss of revenues, inaccuracies in meter reading activities and also difficulties in preventing unwanted use of energy and controlling peak time load. Enormous research has been done in combating some of this highlighted challenges however, there are still some fundamental issues with existing meter solution which includes high cost of implementation and training, high rate of user's involvement and maintenance issues. Therefore, there is a need for an automatic, low cost and effective metering system which has the ability to successfully and accurately read a metering system and transmit the energy readings to a utility station through a suitable communication infrastructure. This paper however, aims to design an automatic energy metering system with the capacity to transmit energy meter readings from meters to a utility provider. To achieve this, a real-time monitoring system for generating billing information with security features for theft detection and remote disconnection of meters (Prachi, 2014) was proposed.

The rest of the paper is organized as follows. Related work is presented in section 2. Section 3 presents the methodology for the study while section 4 gave a detailed discussion on the system implementation and result obtained. The study is finally concluded with a recommendation for future research work in section 5.

LITERATURE REVIEW

This section reviews some related works on Automatic Energy Metering (AEM) system and it is based on six different technologies as shown in Figure 1. Table 1 gives a comparison

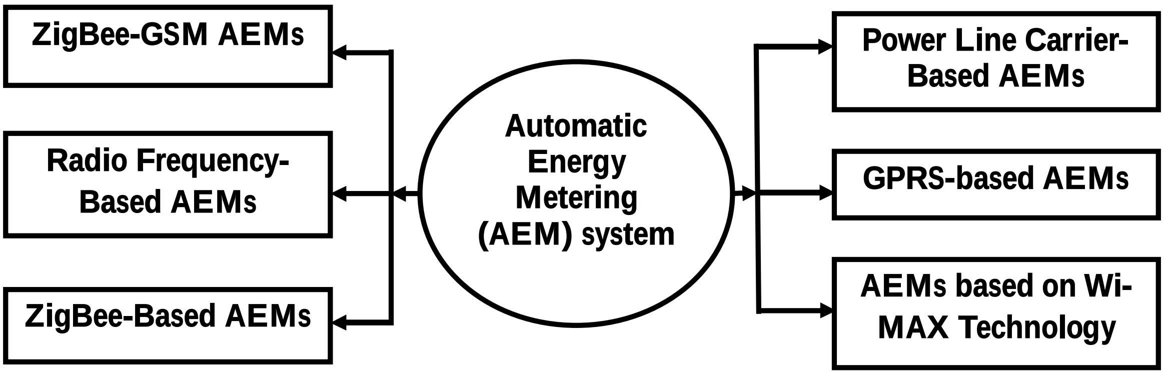

Figure 1: Categories of Existing AEMs Technology

Table 1: Comparison of Various Wireless Protocols (Saad *et al.,* 2014)

Protocols	Bluetooth	ZigBee	WiFi	WiMax	GSM/GPRS
Success metrics	Cost, convenience	Reliability, power, cost	Speed, Flexibility	Through-put, Speed, Range	Range, Cost, Convenience
Frequency	2.4 GHz	868/915 MHz	2.4 GHz	2.4; 5.1- 66 GHz	850/900; 1800/1900 MHz
Nominal TX power	0 - 10 dBm	-25 - 0 dBm	15 - 20 dBm	23 dBm	0-39 dBm
Nominal range	10 m	10 - 1000 m	10-100 m	0.3-49 Km	2-35 Km
Channel bandwidth	1 MHz	0.3/0.6 MHz; 2 MHz	25-20 MHz	20;10 MHz	200 kHz
Max signal rate	720 Kb/s	250 Kb/s	54 Mb/s	35-70 Mb/s	168 Kb/s

RF-based automatic metering system is the most common types of metering systems which include the handheld, mobile and fixed network (Prachi, 2014). Despite the advantages of using RF technology such as reduced meter reading time, it however has some limitations such as reduced range of radio signals, susceptibility to interferences from weather conditions, difficulty in receiving from some specific areas shielded by structures e.g. mountains (Ali *et al.,* 2012). EPRI (EPRI, 2010) also stated that RF exposure may be hazardous to consumers, therefore this technology is not suitable for meter reading.

Authors in (Joongwong, 2007; Knauth, 2008) presented an AEMs based on ZigBee technology. This technology was built using home area networks for connecting meter devices. Although, the proposed system by (Knauth, 2008) was able to reduces man-power requirement but requires consumer's involvement which require constant pictures of the energy meter in their premises to the provider. It also requires ZigBee networks to be installed at different locations in the country due to its short range (<10m) and a low data speed. Hence, requires different ZigBee networks to be deployed across a specific geographical region (Prachi, 2014). The use of GSM-based AMRS counters the limitation posed by the ZigBee-AMRS thereby providing large range and high data speed when compared with ZigBee technology. The shortcomings of this technology include high consumers' intervention via sending pictures of meter reading before it can be monitored remotely. In addition, it is capital intensive to build a ZigBee network.

Quan-Xi, (2010) and Arun, (2012) presented a GSM and ZigBee based Automatic Meter Reading System. The authors stated that the proposed system was able to take electric energy reading of large power consumers while Dongre, (2014) and Primicanta, (2010) proposed a GSM technology using the SIM300 GSM modem. The proposed system uses a power saving techniques as low as 2.5mA. The system reduces the cost of using only ZigBee network by incorporating GSM technology for low cost meter reading system thus providing efficient services to the consumers. The limitations include slow communication process for many users due to its low data rate transfers. Unlike ZigBee technology, distance is a major setback in Bluetooth AEMs (Newbury and Miller, 2002) due to its close range factor for effective data transfer at a very low speed.

Kumar and Ballala, (2012) developed a GPRS-based Automatic Metering System using the advancement in the mobile communication technology to reform electricity market. This technology measures the energy reading from a meter regularly. The data obtained are sent to the utility centre through SMS. However, GPRS-based AMRS in this paper was mainly for monitoring purposes and generation of the appropriate billing information at the required period. It has no system set up to detect energy theft and has no remote disconnection capability.

Ke-he *et al.,* (2010) designed a GPRS and web-based automatic metering system. The system utilizes the internet and GSM modules to monitor electricity consumption. The strength of the work is the ability to obtain real time data from energy meters and its supports for wide coverage area communication and easy maintenance. The system is however, capital intensive due to the cost of managing and maintaining a web services. Ahmed *et al.,* (2012) developed a WiMAX-based Automatic Metering System. The system was divided into four units and the strength includes: high performance, high data rate and high coverage area. The WiMAX technology provides AMRS process with good efficiency and reliability, however it is complex to implement and capital intensive. Poonam, (2013) developed a PLC-based automatic metering system which allows data from energy meter to be sent over existing electric power lines. The strength of the system is the usage of limited cables for communication since it allows the use of existing electric power cables. Therefore, controlling, monitoring, and transfer of consumers' energy data are made possible via existing power lines. The major disadvantage of PLC technology is signal interference and the inability to transmit data on high voltage side of a power system (Cogency, 2014).

However, our proposed system was designed to mitigate the following limitations as identified by existing literatures:
(1) Reduces management, maintenance, and start-up cost significantly.

(2) Incorporating energy theft detection system through remote disconnection.
(3) Effective data transfer speed with better coverage when compared with Bluetooth and ZigBee technology.
(4) Reduces design complexity and easy to deploy when compared with the microprocessor-based AMS.

Table 2: Summary of Related Works

Authors	Title	Methods	Strength
Yip *et al.* (Yip *et al.*, 2017)	Detection of energy theft and defective smart meters in smart grids using linear regression	Linear Regression and Categorical variable model	Ability to detect energy theft caused by meter tampering and detect defective smart meters.
Liu (Liu, 2012)	Wireless Automatic Meter Reading System based on Next Generation Broadcasting	Next generation broadcasting method	Cheap and combines the radio and TV network for transmission
Arora and Taylor (Arora and Taylor, 2016)	Forecasting electricity smart meter data using conditional kernel density estimation	Incorporates conditional kernel density (CKD) estimation with a decay parameter	Reduce cost significantly for majority of consumers
Aziz *et al.* (Aziz, *et al.*, 2013)	Artificial Intelligent Meter development based on Advanced Metering Infrastructure technology	Artificial Intelligence Metering (AIM) techniques	Facilitate consumers to manage their energy usage wisely
Ahmad (Ahmad , 2017)	Non-technical loss analysis and prevention using smart meters	Linear Regression	The system was able to monitor and detect energy theft
Ashna and George (Ashna and George, 2013)	GSM-based Automatic Energy Meter Reading System with Instant Billing	GSM-based wireless communication module	Minimal human interaction
Ahmed (Ahmed ,2012)	Automatic Electricity Meter Reading System: A Cost-Feasible Alternative Approach for Bangladesh perspective	Digital wattmeter and WiMAX technology	Low-cost and author claimed it will reduce electricity corruption

DESIGN METHODOLOGY

The methodology for this study involves the description of the system model, simulations and every other detail required for the successful design and construction of the proposed.

The Automated Energy Metering System using GSM Technology (AEMS_GSM)

This study presents a simple and an automated energy metering system using on GSM technology (coined AEMS_GSM). The system architecture consists of four functional sections which include the Metering Circuits, Power supply, PIC Micro-controller and the Communication section. The functional block diagram of the Automatic Metering System using GSM (AEMS_GSM) is represented in Figure 2 and the complete schematic diagram of the AEMS_GSM is represented in Figure 3. The architecture in Figure 2 and Figure 3 shows how the different sections of the metering system are connected for full functionality.

Metering Circuits

This phase consists of voltage and current sensing circuits which is used to sense the voltage and current consumed by the load. For this study, the sensing circuits are used to reduce the cost of constructing an energy meter. The potential transformers and the current transformers are both used to sense voltage and current reading in the load.

The Analysis of the voltage and the Current sensing circuits for this study is listed described below.

Voltage Sensing Circuits: For this study, a step-down transformer was used to step down 240VAC supply from the mains to 12VAC. Therefore, turning the ratio of the transformer used to 20:1. Equation 4 depicts the Transformer ratio while equation 5 gave a mathematical expression for calculating voltage divider circuit. The Figure 4 shows the voltage sensing circuits.

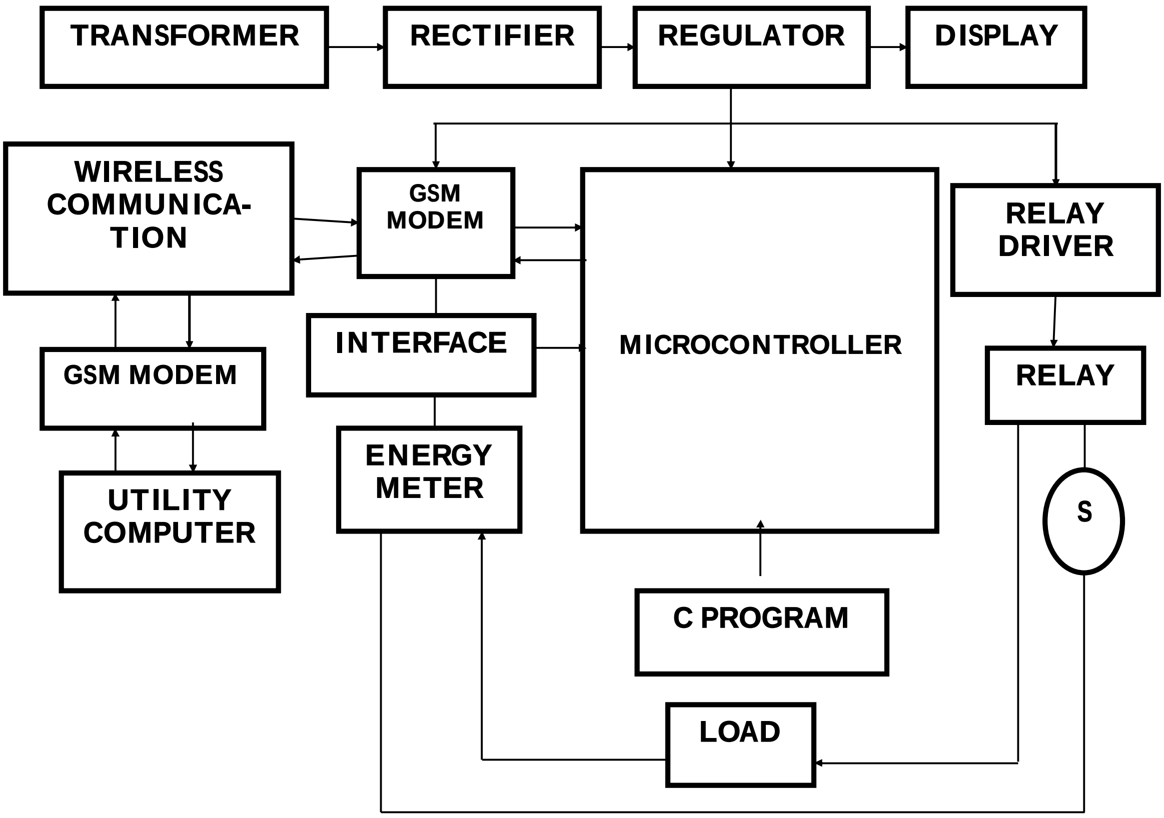

Figure 2: Functional block diagram of the AEMS_GSM

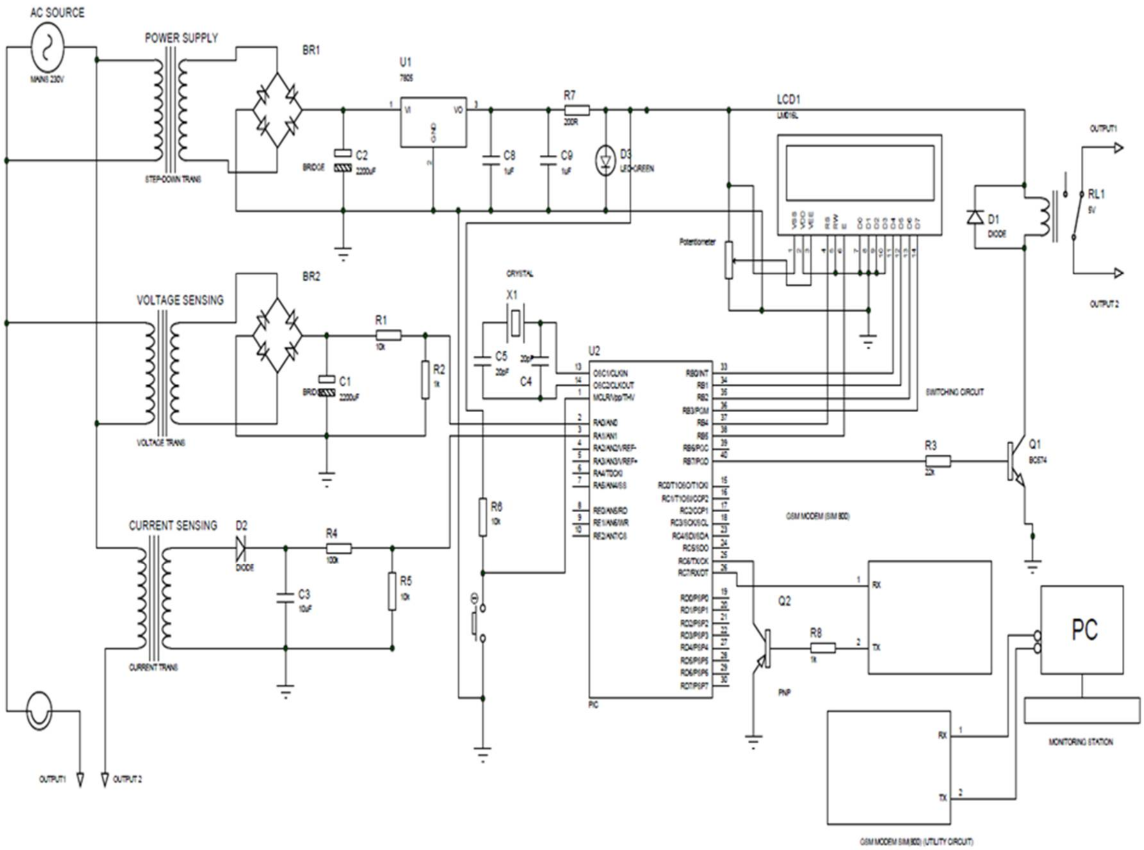

Figure 3: Complete Schematic diagram for AEMS_GSM

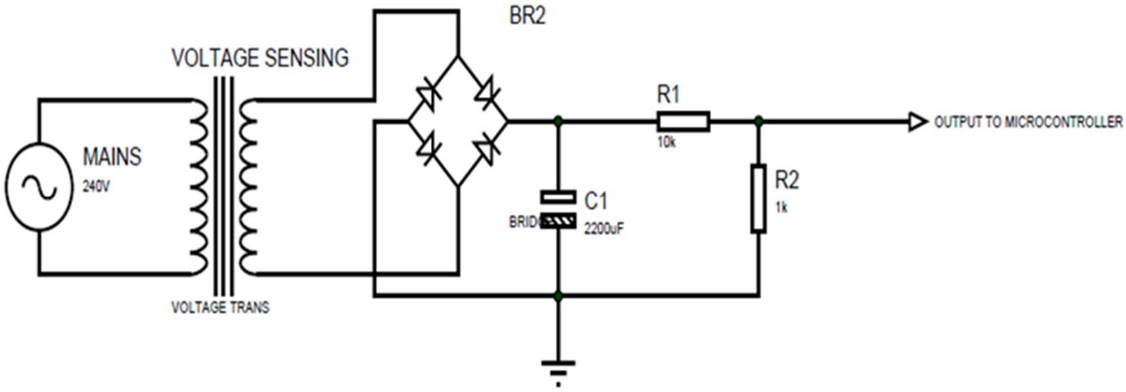

Figure 4: Voltage sensing circuit

Analysis of the Voltage Sensing Circuit:
Transformer ratio of potential transformer used,

$$240/12 = 20/1 \quad (4)$$

Using the voltage divider circuit,

$$V\_(OUT) = (V\_IN \times R\_2)/(R\_1 + R\_2) \quad (5)$$

V_{IN} =12V, R_1 = 10K, R_2 = 1K

$V\_(OUT) = (12 \times 10^3)/(10^4 + 10^3)$ = 1.0909V

To protect the microcontroller from high voltage, the maximum amount of voltage that would be sensed by the ADC port of the controller is 1.09099V. The values read by the ADC port of the microcontroller is multiplied by as scaling factor to obtain the actual voltage value read by the potential transformer.

Current Sensing Circuits: The measurement of alternating electric current is done by using a current transformer which was used to observe the flow of current by reporting the accurate current usage and phase angle to the microcontroller. The current sensing circuit was designed in such a way that it connects to the microcontroller at the output and in series to the load at the input as shown in Figure 5.

Analysis of the Current Sensing Circuit:
Current transformer is rated 1V/Amp, therefore at 5A current for standard current transformer, 5V is induced at the secondary winding.

Using the voltage divider circuit:

$$V\_(OUT)=(V\_IN\times R\_2)/(R\_4+ R\_5) \quad (6)$$

V_IN= 5V, R_4 = 100K, R_5 = 10K

$$V\_(OUT)=(5\times104)/(105+104)= 0.4545V \quad (7)$$

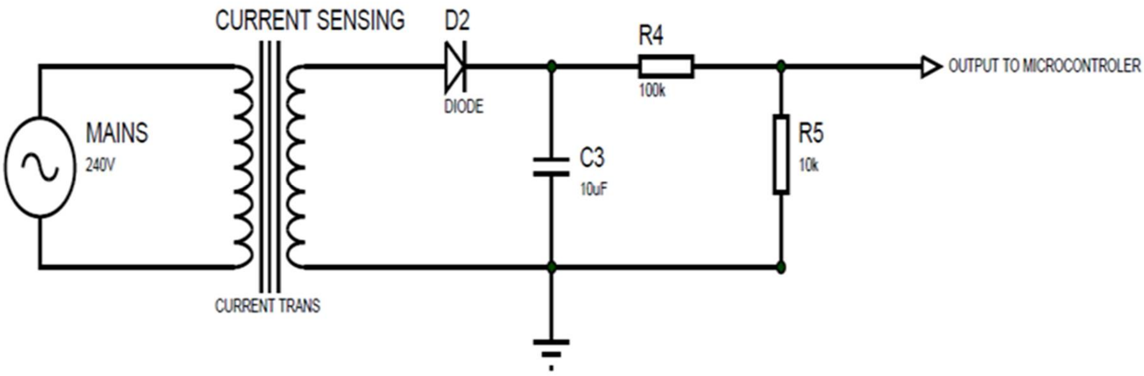

Figure 5: Current sensing circuit

Power Supply Unit

The power unit for this study supplies 5VDC to the PIC microcontroller, GSM module and the LCD. The mains voltage 240VAC is supplied to the transformer which steps it down to 12VAC. AC voltage output is converted to pulsating DC voltage by the bridge diode. Capacitor C2 is used to filter the pulsating output of the bridge rectifier. The 7805-voltage regulator is used to maintain a constant output voltage of 5V. The input voltage of the regulator should not exceed 35V as stated in the device datasheet. From Equation 5, the condition is met since V_(L(DC)) = 9.913V. Capacitors C1 and C3 are decoupling capacitors used to prevent electromagnetic interference from interfering with the supply to the microcontroller. Typical values of 100µF and 100nF is used. The LED acts as an indicator lamp to show that the power supply is functioning. The resistor R1 acts as a current limiting resistor for the LED to reduce the current passing through the LED.

Microcontroller Section

This is responsible for computing power calculations and displaying the value obtained on the LCD. The controller is also used to automate the meter reading process by interfacing a GSM modem. The GSM modem is responsible for communications between the energy meter and the remote PC. The PIC microcontroller used is the PIC18F452 which is a low power consumption device with 40-pin high performance microcontroller as shown in Figure 6. This PIC18F452 is powered by 5VDC from the power supply section and it reads the voltage and current value obtained from the sensing circuits through its AN0 and AN1 ports. The analog values are converted into digital values using the A/D feature of the microcontroller. In addition, the PIC18F452 computes the energy reading and accumulates its result in the register and the values are displayed on the LCD in kWh.

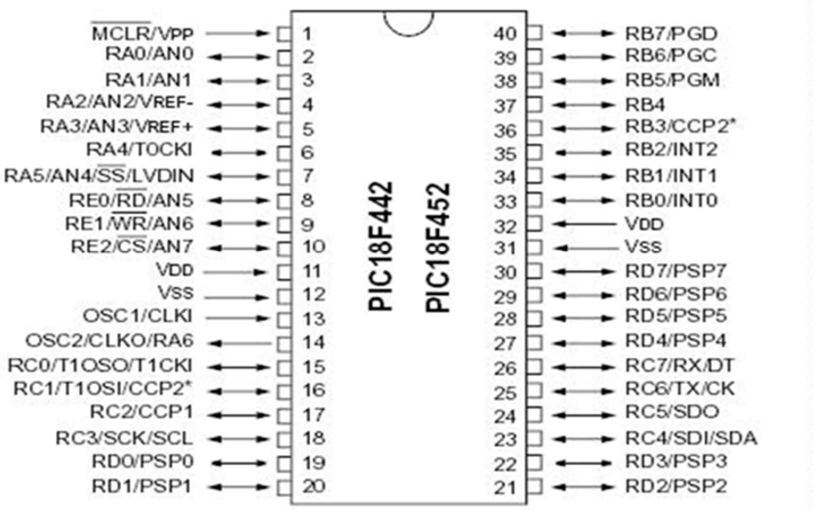

Figure 6: PIC18F452 microcontroller Pin Configuration

Communication Section

The communication section of this study is responsible for bi-directional communication between the meter and the remote Personal Computer (PC). This section enables the sending and receiving of information such as disconnection signal and meter readings from the PC and energy meter respectively. The main device that is responsible for communication between the meter and the PC is the GSM modem. The GSM modem used in this study is a SIM 800 that is based on subscription to an operator thereby providing connectivity. However, the GSM modem requires a set of machine instructions known as Attention (AT) commend set which enables the activation of various features on the modem.

For the GSM modem to interface with the microcontroller there is a need for a compatibility check of the transmitter (TX) and the receiver (RX) pins through the aid of a PNP transistor. The GSM module used in this study uses a 4.2VDC supply voltage; hence a potentiometer (LM317) is used to reduce the 5VDC from the power supply in order to power the GSM module. Figure 7 shows the flow diagram for the automatic metering system.

IMPLEMENTATION AND RESULTS

The implementation of this system is divided into two (2) main categories:
(1) Hardware implementation
(2) Software implementation

Hardware Implementation

The hardware implementation involves the bread boarding of component to the mounting and soldering of component to the complete packaging. Prior to the construction of this project, the various components used for the project were bread boarded to ensure that all the components are functioning properly. This was also done to ensure the correctness of the circuit diagram before mounted on the Vero board for permanent soldering. A plastic case with the LCD projecting from the top of the casing was designed considering a low cost design.

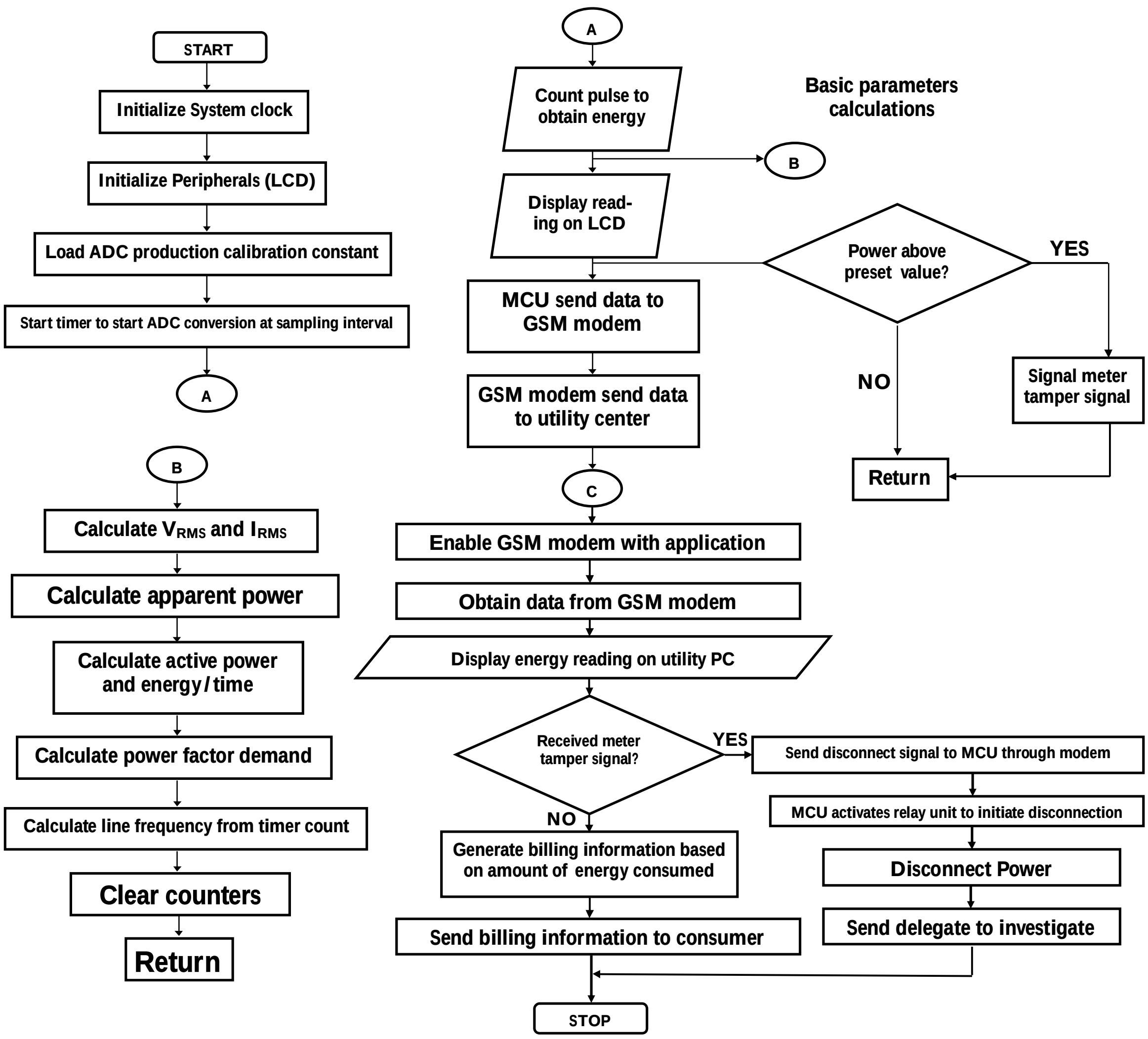

Figure 7: Flow diagram for the Automatic Metering System (AEMS_GSM)

Software Implementation

This subsection entails the coding of the PIC18F452 microcontroller using MikroC and the GUI on the personal computer using Visual basic. After compiling the program for the microcontroller, it was converted into a .hex file which was then loaded into the microcontroller using a PIC programmer. The algorithm for the automatic metering system is shown in Figure 8.

Testing

Different tests were carried out to monitor and verify the operations and performance of the metering system. The key tests used in this study include:
(1) Unit Testing
(2) Integration Testing
(3) System Testing

Unit Testing:

The metering system consists of different units which were coupled together to obtain the whole system. Tests on units independent of one another were carried out such as the resistance and capacitance values before circuit connections. The transformer was tested to ensure that it provides the necessary voltage levels when it is connected to the mains. The diodes, transistors, capacitors and resistors were also tested to ensure that they were functioning properly.

Power Supply Unit Testing: The power supply unit consists of the step-down transformer, the bridge diode, capacitors and voltage regulator. The tests were carried out at different outputs of these components to ensure that the required wave form and AC or DC voltage levels are obtained.

Communication Unit Testing: The communication unit consists of transistors, the GSM module, potentiometer and the PC. All tests were carried out at various outputs to ensure that the required results are obtained.

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ALGORITHM FOR THE AUTOMATIC ENERGY METERING SYSTEM USING GSM (AEMS_GSM)
Input:      {system clock Timer (C), LCD, Microcontroller unit (MCU), GSM modem;
            Load ADC production calibration constant, Load gain calibration constant;
            Energy reading on utility PC (ERUP), Energy reading on the consumer meter (RCM)};
Output: {Meter Tampering Signal (MTS), Billing Information};
Initialize Clock Timer C = 0;
Process:
            Step 1:  ∀  Timer  ∈  {Load ADC calibration, Load gain calibration constant};
            Step 2:     Count     Pulse C to obtain energy usage;
            Step2: Calculate the basic parameters for energy usage:
                  i.        V r.m.s and I r.m.s
                  ii.       Apparent power
                  iii.      Active power and Energy Time using Equation 1, 2 and 3.
                  iv.       Power factor demand
                  v.        Frequency from timer count
            Step 3: Display reading on the LCD;
            Step 4: Enable GSM modem application to:
                  i.        Obtain data from the modem
                  ii.       Display energy reading on utility PC;
            Step 5: Check for meter tampering signal;
            Step 6:  if (ERUP != RCM) {
            Step 7: Do these:
                  i.        Send meter tampering signal
                  ii.       Send disconnect signal to MCU
                  iii.      MCU activate relay unit
                  iv.       Alert delegate to start an investigation
            Step 8:   }
            Step 9:   Else if (ERUP==RCM) {
            Step 10: Do these:
                  i.        Generate billing information based on the amount of energy consumed
                  ii.       Send billing information to the consumer
            Step 11:  }
            Step 12:  Stop
```

Figure 8: Algorithm for the Automatic Metering System

Integration Testing

To evaluate the interaction between separate modules of the project, the integration testing was carried out. This was important because the project involves the integration of several components to obtain a complete system. The test was about connecting the power supply unit, the microcontroller, metering section and the communication section together. Table 3 shows the various voltage flows for power supply units, sensing unit, transformer and the input at the GSM modem.

Table 3: Various voltage flow

S/N	Outputs/Inputs	Expected values (V)	Practical values (V)
1	Output at Power Supply Unit	5.0	5.01
2	Output at Current sensing unit	0.45	0.5
3	Output at Voltage sensing unit	1.09	1.3
4	Output at step down transformer	12.0	13.05
5	Input at GSM modem	4.2	4.0

From Table 2, it can be observed that there is a close range of between the output values as regards to expected values and practical values, therefore it can be deduced that the proposed system gave a nearly optimal result which can be further expressed in Figure 9.

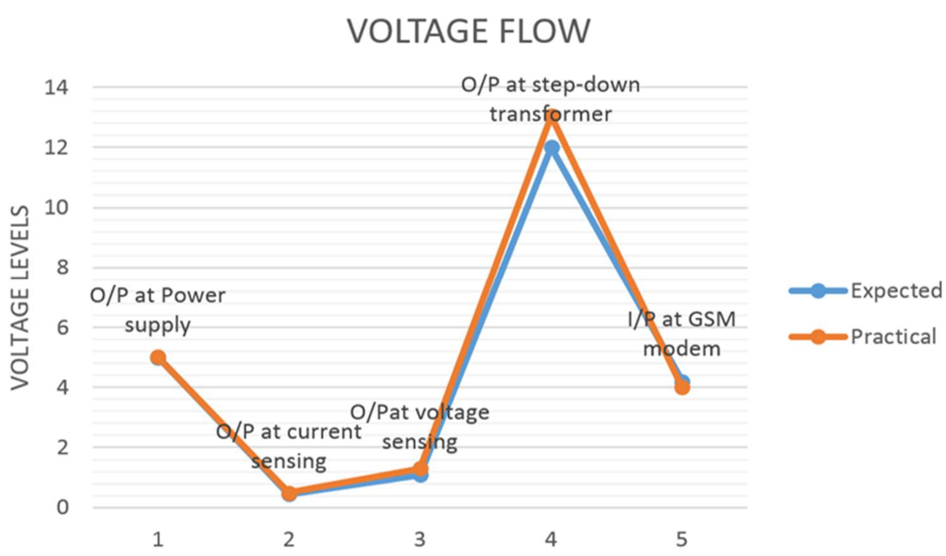

Figure 9: Graphical representation of voltage flow

Table 2 depicts the various voltage flows obtained at different outputs of the study where the maximum, the voltage entering the ADC port is 0.4545V. The expected values obtained during the system design and the practical values obtained during the implementation of the project are also compared. Figure 8 shows the graphical representation of the voltage flow at different outputs and inputs in this project. From Figure

2, the practical values obtained in this study were very close to the expected values.

System Testing

System testing was done to test the complete metering system. This involves the complete operation of the system based on the interaction between the different modules. It involves obtaining the meter readings from the test loads and sending the required data to the personal computer. The test load also disconnects from the power source automatically once the preset energy limit has been exceeded.

CONCLUSION

An Automatic metering system using GSM technology (AMS_GSM) was designed, implemented and tested. This system gives a revolutionary advancement in the innovation of energy metering which considers the concept of a two-way wireless communication technique and accurate measurement of electric energy used by a consumer load. The testing shows a near accurate result when comparing the practical testing values to the expected testing values hence, energy meter could be advanced to give a better and accurate reading with efficient energy calculations. Therefore, this study can also contribute to the development of smart grids to make the delivery of electric energy reliable and properly accounted for. Challenges encountered during the implementation are the difficulty in analysing and calculating the necessary values and results required for this study.

Future research can be carried out by using smart energy metering IC such as ADE7166 or ADE7169 to interface directly to an LCD thereby eliminating the use of a microcontroller which can be difficult to program and incorporating method such as inspection and comparison energy theft detection instead of bypass detection used in this study.

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